Aviation Research Lab
Institute of Aviation

University of Illinois
at Urbana-Champaign
1 Airport Road
Savoy, Illinois 61874

UP OR DOWN? A COMPARISON OF HELMET MOUNTED DISPLAY AND HAND HELD DISPLAY TASKS WITH HIGH CLUTTER IMAGERY

Michelle Yeh, David Brandenburg,
Christopher D. Wickens, and James Merlo

Technical Report ARL-00-11/FED-LAB-00-3

August 2000

Prepared for

U.S. Army Research Laboratory
Interactive Displays Federated Laboratory

Contract DAAL 01-96-2-0003

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **AUG 2000**	2. REPORT TYPE	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **UP OR DOWN? A COMPARISON OF HELMET MOUNTED DISPLAY AND HAND HELD DISPLAY TASKS WITH HIGH CLUTTER IMAGERY**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Army Research Laboratory,Aberdeen Proving Ground,MD,21005**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT
The trade-offs between the costs of increasing clutter by overlaying complex information onto the forward field of view using a helmet-mounted display (HMD) versus the cost of scanning when presenting this information on a hand-held display were examined. Eight National Guard personnel were asked to detect, identify, and give azimuth information for targets hidden in terrain presented in a simulated far domain environment while performing a monitoring task in the near domain using either a HMD or hand-held display. The results revealed that the costs of clutter outweighed the cost of scanning as the amount of information that needed to be inspected increased. The presentation of cueing which guided attention to a large region around the target facilitated detection without imposing the costs of attentional tunneling.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**16**	

ABSTRACT

The trade-offs between the costs of increasing clutter by overlaying complex information onto the forward field of view using a helmet-mounted display (HMD) versus the cost of scanning when presenting this information on a hand-held display were examined. Eight National Guard personnel were asked to detect, identify, and give azimuth information for targets hidden in terrain presented in a simulated far domain environment while performing a monitoring task in the near domain using either a HMD or hand-held display. The results revealed that the costs of clutter outweighed the cost of scanning as the amount of information that needed to be inspected increased. The presentation of cueing which guided attention to a large region around the target facilitated detection without imposing the costs of attentional tunneling.

1. INTRODUCTION

The ground soldier of the future will be asked to perform a multitude of tasks given various sources of electronic data. Consider, for example, the task faced by the ground soldier who must attend to and integrate information regarding enemy and friendly unit positions and movement in order to determine his own course of navigation. To support the soldier’s task, technological advances in automation will one day avail designers the opportunity to present intelligent cueing information to guide attention throughout the scene in such a way that it is either overlaid on the forward field of view using helmet-mounted display (HMD) technology or in a more traditional head-down hand-held display.

The use of an HMD allows the user to perform tasks with a head-mounted “guide” and reduces scanning and head movement to access information which would otherwise be presented in a head-down format. However, the clutter of overlapping images in the forward field of view is increased so that in a worst case scenario, the symbology on the display may obscure information in the far domain. A meta-analysis comparing the presentation of information head-up versus head down in the context of air and ground vehicles revealed that the costs of scanning, associated with head down presentation, generally outweigh the costs of clutter, associated with head up presentation (Fadden, Ververs, and Wickens, 1998). However, the research also indicates that the clutter costs become greater and more disruptive as more information is added to the head-up display (Ververs and Wickens, 1998).

In addition to its added clutter, the presentation of information on an HMD is also more compelling than using a head-down format. Yeh, Wickens, and Seagull (1998) reported that subjects were *less* likely to constrain their search field when information was presented on a hand-held display. In their experiment, subjects were presented with cueing information which guided their attention to the location of targets in a battlefield scenario. When using an HMD, subjects were faster at detecting targets in the world but also exhibited more *attentional tunneling*, an overreliance on the cueing information such that they were more likely to miss the presence of an unexpected, but high priority target located elsewhere in the visual field. This effect was mediated by the display location (Yeh et al., 1998, Exp. 2) and the precision of the cueing information (Merlo, Wickens, and Yeh, 1999). That is, when cueing information was presented in a less real format on a hand-held display (as in Yeh, Wickens, & Seagull, 1999) or when the precision of the cueing information *decreased* (as in Merlo et al., 1999), then such attentional tunneling decreased and subjects were more likely to scan the surrounding environment rather than simply rely on the cue. Thus, one way to capitalize on the benefits of cueing and reduce the costs of tunneling may be to guide attention to a wider region in space by reducing the spatial precision of the cue without changing the reliability of the cue.

In the studies reported above, subjects performed tasks using a see-through HMD in the head-up condition, and the symbology which was presented was relatively sparse. However, the availability of an HMD in today’s military as well as many other environments in which “wearable computers” are designed to present information superimposed on the outside world would allow designers to present not only cueing information, but also a host of other information, such as navigational data, weapons status, and friendly and enemy troop locations.

At a minimum such presentation imposes new demands and requires that the display allow the completion of tasks of focused attention (e.g., on terrain or other information presented on the display and for friendly troop location in the real world) and divided attention (e.g., integrating cueing information presented on the display to find target location in the real world). Thus, while the previous experiments revealed an overall benefit to the HMD, implying that its reduced scanning benefit (relative to the hand-held display) outweighed its increased clutter cost (from overlapping imagery), we anticipate that this trend might be reversed when the display contains considerably more information than that used by Yeh et al. (1999) and Merlo et al. (1999). One feature of the current experiment will be to employ a more information-rich display than that used previously.

Besides the incorporation of more information on the display, a second change in the current paradigm from that used by Yeh et al. (1999) is to provide cueing with less spatial resolution or precision. We anticipate that this change should both reduce the overall attentional tunneling effect (as had been observed by Merlo et al., 1999) and reduce the particular susceptibility of the HMD to that tunneling.

In the current experiment, subjects were presented with cueing information which guided attention to a 45° region in space and topographical data depicting enemy position. This information was presented either head-up using a monocular, semi-transparent HMD, or head-down on a hand-held display. Our interests were whether the costs of increased scanning to data on a head-down hand held display outweighed the increasing clutter on the HMD, and the degree to which the reduced cue precision increased attentional breadth (i.e., reduced attentional tunneling).

2. METHODS

2.1 Subjects

Eight military personnel (6 members of the Illinois Army National Guard, 1 member of the Air National Guard, and 1 member of the Marine/Navy Reserve Officers Training Corps) participated in the experiment.

2.2 Task Overview

The task performed by subjects consisted of three stages: (a) target detection, (b) target identification, and (c) reporting target heading. The target *detection* task (the primary task) required subjects to scan the display looking for any one of four target objects: three of the targets were presented on a total of 90% of the trials (30% each) and were therefore expected; the fourth was presented only 10% of the time and was unexpected. Subjects were not told which target to search for. While searching for the target, subjects were asked to perform a monitoring task, displayed on either a simulated HMD or a hand-held display, which stopped once the target was found.

Cueing of the target's location was presented for half the expected targets to aid the detection task; the unexpected target, whose detection performance was used to infer attentional tunneling, was never cued. Targets were presented serially; only one target was displayed at any time, except in the case of the unexpected target, which was always presented in conjunction with an expected target. However, only one object was detected per trial. Subjects were instructed that detecting the unexpected target – a nuclear weapon – took precedence over standard target detection.

Once the target was found, the subject was required to *identify* the target as either friend or foe and give the target's *heading*, the current compass direction of the target with respect to his current location.

2.3 Apparatus

The terrain was displayed on the walls of the Cave Automatic Virtual Environment (CAVE), a 10x10x9-foot room sized video environment. The subject was seated in the center of the CAVE.

Subjects wore a standard issue Army helmet on which a Flock of Birds head tracker was attached. In the head-up condition, we simulated the use of an HMD by displaying symbology biocularly in the subject's forward field of view. The display subtended approximately 15° of visual angle. In the hand-held condition, subjects viewed the image presented on a hand-held display with a 2.5" screen. They were required to wear sunglasses, which reduced the salience of the far domain targets to a level equal to that of the view through the shutter glasses, simulating the HMD. This adjustment was designed to equate the visibility and detectability of the targets in the two display conditions. The symbology on the hand-held display was visible to both eyes.

2.4 Tasks

The displays were created from static two-dimensional renderings of three-dimensional images depicting hilly terrain. The terrain was developed using geographical data of Austin, TX, Detroit, MI, and Jordan Valley, UT, downloaded from the U.S. Geological Survey web site. The target stimuli, shown in Figure 2.4.1 were placed in the terrain.

(a) (b) (c) (d)

Figure 2.4.1. Stimuli. Target objects consisted of: (a) tank, (b) soldier, (c) land mine, and (d) nuclear device.

The tanks, soldiers, and nuclear devices were camouflaged, i.e., colored in shades of brown, green, and black; land mines were presented in black. Since the shading of the terrain varied, the intensity of the targets was adjusted adaptively at each location so that the contrast ratios between the target and the terrain were similar for all targets. The greater salience of the nuclear device was insured by presenting them at a higher contrast ratio with the background than the other three targets. This was done in order to insure that any deficits in nuclear target detection, attributed to attentional tunneling, could not be attributed instead to a lower visibility. The location of tanks and 50% of the land mines was cued with a dynamic arrow pointing in the direction of the target, based on the subject's current head position. All soldiers and 50% of the land mines were uncued. The presence of cueing was randomized (i.e., unpredictable) over trials.

Friend-or-foe identification was based on the direction in which the target was pointing. Friendly targets pointed towards the left and enemy targets pointed towards the right. No identification was required if the target was a land mine or nuclear device.

2.5 Displays

An example of the terrain environment is presented in Figure 2.5.1, which depicts the symbology superimposed onto the far domain.

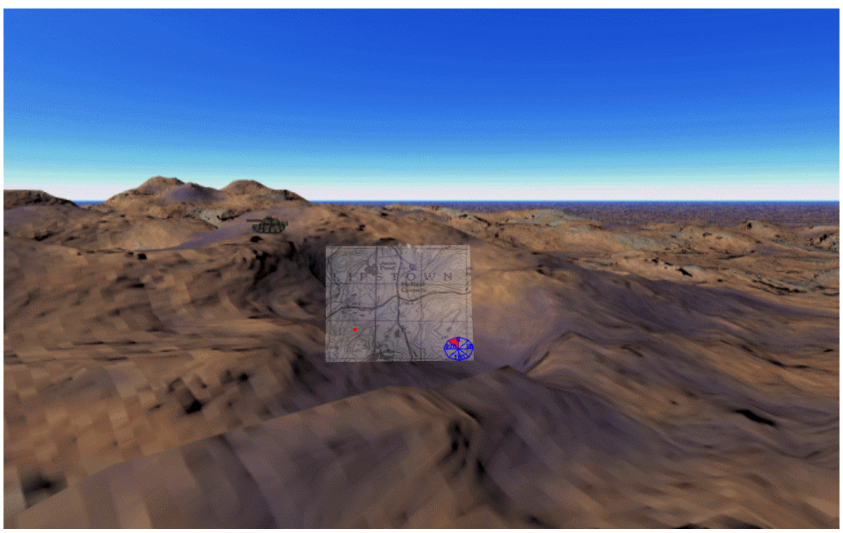

Figure 2.5.1. HMD symbology, superimposed onto the far domain.

In Figure 2.5.1, the pictures show the HMD imagery superimposed onto the terrain presented on a CAVE wall. The visual region of HMD-depicted information was 15° laterally x 15° vertically. Note that the imagery is translucent and not opaque, i.e., subjects were still able to see the far domain and its targets through the head-up information. The imagery consisted of a map, supporting the secondary task, and a "pie," in the lower right corner, designed to support target cueing in the far domain.

An enlarged image of the HMD symbology is presented in Figure 2.5.2.

Figure 2.5.2. HMD imagery.

As shown in Figure 2.5.2, the map was black-and-white; the pie in the right corner of the HMD image was presented in blue; all other symbology (cueing and data for the monitoring task) were presented in red. The pie symbology was used to represent the location of targets, when they were cued. Each region in the pie corresponded to a 45° region in the CAVE. Figure 2.5.3 graphically depicts a top down view of this relationship.

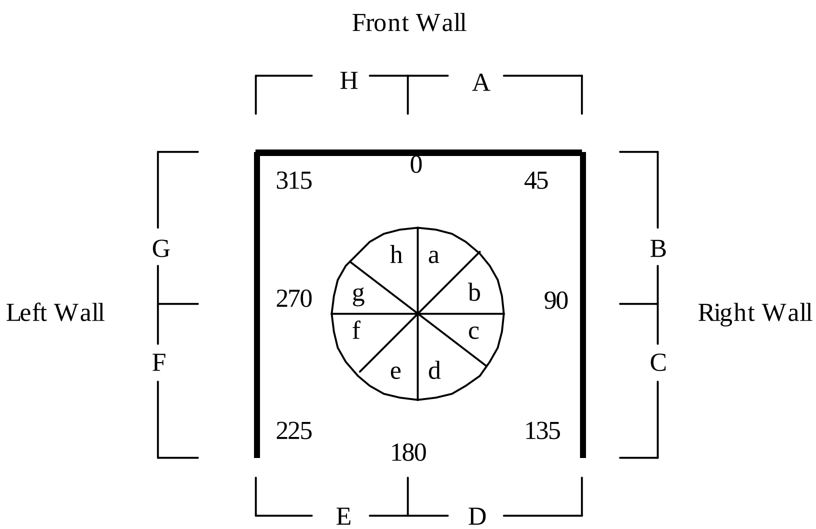

Figure 2.5.3: Top down view of CAVE.

The three bold lines represent the CAVE walls; thus, section *a* of the pie corresponded to section A of the CAVE, and represented an area between 0° and 45°, section *b* corresponded to an area between 45° and 90°, etc. Note that the CAVE has a field of view of 270°; consequently, the target could never be presented in sections D and E, where there is no wall. Heading locations of 0°, 90°, 180°, and 270° were labeled on the pie. When cueing was available, a 45° region of the pie was highlighted to indicate the approximate location of the target in world (i.e., CAVE) referenced directions. The presentation of the cueing information, i.e., the region highlighted in the pie, was not updated based on momentum head orientation. In Figure 2.5.1, the highlighted section cues the location of the tank at approximately 355° (note that the center of the figure was 0°).

In the head-down conditions, the HMD imagery was presented on a hand-held 2.5” Casio TV. The display subtended approximately 3° of visual angle, when it was held at the typical viewing distance.

While conducting the searches in either the HMD or the hand-held condition, subjects wore an Army issue Kevlar helmet with a head tracker attached to the top center of the helmet to collect head movement in the *x*, *y*, and *z* directions. Note that in both head-up and head-down conditions, the imagery was independent of the subject’s head or hand orientation; in other words, the presentation of the cue did not change when the target was within the subject’s field of view. However, there were inherent differences in the presentation of the symbology on the HMD versus the hand-held display: (1) the symbology presented in the head-up display required the subject to cognitively rotate the pie to a horizontal position in order to find the target, and (2) the resolution of the imagery on the HMD was greater than that of the hand-held display.

2.6 Monitoring Task

Subjects were asked to monitor the position of an enemy aircraft and indicate (with a button press) when the aircraft moved over any roads presented on the map. The position of the aircraft was depicted as a red circle; in Figure 2.5.1, this vehicle is in the southwest quadrant of the HMD imagery. The momentary heading of the aircraft was randomly generated but as it moved over a road, it remained over the road for 5 seconds, or until subjects responded to the task. Responding early, i.e., before the aircraft moved over a road, was considered to be a false alarm and had no effect.

2.7 Experiment Design

The experiment employed a within subjects design. Subjects performed the task with both the HMD and hand-held display. The order with which the displays were presented was counterbalanced.

Six different terrain views, created from taking static “pictures” at different locations of topographical regions, were used in the experiment. For each viewing condition, subjects were presented with one practice block, consisting of ten search trials, and ten experimental blocks, each containing a set of twenty search trials. The presentation of the expected target stimuli (i.e., tanks, land mines, and soldiers) was serial – that is, only one target was presented per trial and subjects searched the three walls of the CAVE until it was located. The exception was the presentation of the nuclear device, which would appear concurrently with one of the other targets.

Each experimental block consisted of a total of 20 targets; 6 each of tanks, soldiers, and land mines and 2 nuclear devices. Half the tanks and half the soldiers were friendly – the other half were enemy. On a random half the trials, cueing was present. This was the case for all tanks and half of the mines. Thus, the presence of the cueing symbol provided subjects with a partial reduction of uncertainty of target type. Each object appeared twice on each wall, except for the nuclear device which appeared once on the left wall and once on the right wall. Targets were

presented serially, except for the nuclear device, which was presented in conjunction with either a cued target (tank) or an uncued target (soldier). As it was an “unexpected” target, the nuclear device was presented within 15° of either the tank or the soldier with which it was presented in order to maximize the likelihood that the unexpected target would appear in the subject’s field of view as the subject searched for the target (e.g., if the target was a tank located in the center of the left wall, the nuclear device would have been positioned to the right of the tank so that the subject’s field of view would pass over the unexpected target as he moved his head from the center wall to the left wall). In other words, the “unexpected” target was placed in such a position that it would be viewable during the search for the expected target. Note that this constraint, employed also in our previous research (Yeh et al., 1999) was one that biased the results against finding attentional tunneling, relative to the circumstances outside the laboratory where such a constraint would not be present. Subjects were told that a nuclear device could be present on any of the trials, and that its detection should take priority over any other targets.

2.8 Procedure

The experiment took approximately 2.5 hours during which subjects were given the instructions and then performed the experiment. Subjects were instructed to pretend that they were scouts, sent to search for enemies and allies in unfamiliar territory. Their primary task was to find the targets, identify them as friend or foe if relevant (a distinction simulated here by orientation), and send information back to their troop regarding the targets’ position. Their secondary task was to monitor the position of enemy aircraft.

Subjects interacted with the display using a wand and shutter glasses. A diagram of the wand is presented in Figure 2.8.1.

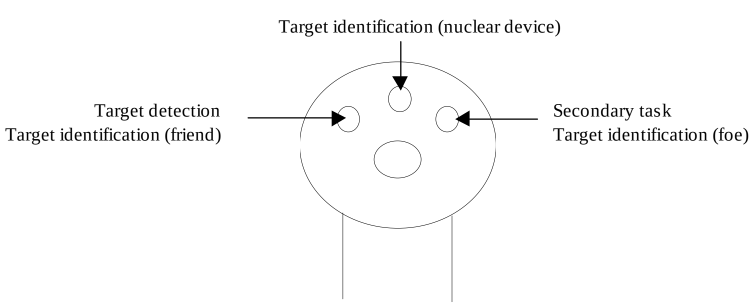

Figure 2.8.1. The wand.

The wand has three buttons and a pressure-sensitive joystick. Only the buttons were used during the experiment to make responses. The joystick was not used at all.

While searching for the target, subjects responded to the secondary task road crossing by pressing the right wand button. To indicate that a target was detected, subjects pressed the left button on the wand. For, the target identification task, subjects then pressed the left button on the wand again if the target was foe, the right button if the target was friendly, or the center button in the case of a nuclear device. Subjects did not need to identify whether the target was a tank,

soldier, or land mine. Note that the button pressed for friend and foe identifications corresponded to the direction the object was pointing, e.g., subjects pressed the left button if the tank or soldier was pointing left. Once the target was detected (land mine) or identified (tank, soldier, or nuclear device), subjects verbally reported its location by stating the target's bearing.

Once the target was detected and reported, the display was darkened. When the subject's head was centered, a subsequent trial, containing a new target, was initiated.

2.9 Performance Measures

The dependent variables collected from the primary target search task were response time and accuracy for target detection, target identification, and target heading. In order to determine whether the symbology influenced the amount of scanning in the environment, data describing the amount of head movement along the x-, y-, and z- axes were collected. Additionally, data concerning the number of times and the amount of time the target was in the view (within 60°, 21°, and 15°) were collected. The center points for the aforementioned view angles are at the center of the HMD and shutter glasses, rather than the momentary gaze direction of the eyes. Thus, it was of course possible for a target to pass through the area in the center 15° of the shutter glasses and go unnoticed by the subject, if his eyes were rotated away from the forward axis of the head.

The measures collected from the secondary task were response time and accuracy. Since each subject took a different amount of time in detecting the targets, the number of events varied. Thus, accuracy for the task was calculated as a proportion of the number of hits to the total number of enemy aircraft position reported.

3. RESULTS

Since it was possible for subjects to mistake a terrain feature for an object, trials with heading errors of azimuth estimation greater than ±20° were assumed to result from this confusion, were scored as incorrect and replaced with the subject's mean response time for like targets in that particular block (i.e., involving the same terrain) displayed on the same wall. This was approximately 10% of the trials. Additionally, outliers which were greater than ±3 standard deviations from the mean were replaced in the same way; this was approximately 2% of the trials.

The data were analyzed to assess (1) the trade-offs between the clutter imposed by the presentation of imagery head-up with an HMD versus the scanning required by the presentation of symbology using the hand-held display, (2) how this trade-off was modulated by the presentation of cueing, and (3) the effects of target expectancy and cueing on target detection.

3.1 Clutter vs. Scanning

The effects of display location were examined by comparing detection performance for each of the expected targets with the HMD versus the hand-held display using a 2 (display: HMD vs. hand-held) x 2 [target type: high salience (tanks, soldiers) vs. low salience (land mines)] x 2 (cueing: cued vs. uncued) x 3 (wall: left, center, right) factor within-subjects ANOVA. Figure 3.1.1 presents the effects of display and target type on response time (left) and accuracy (right). The bars in the figures show ±1 standard errors from the mean.

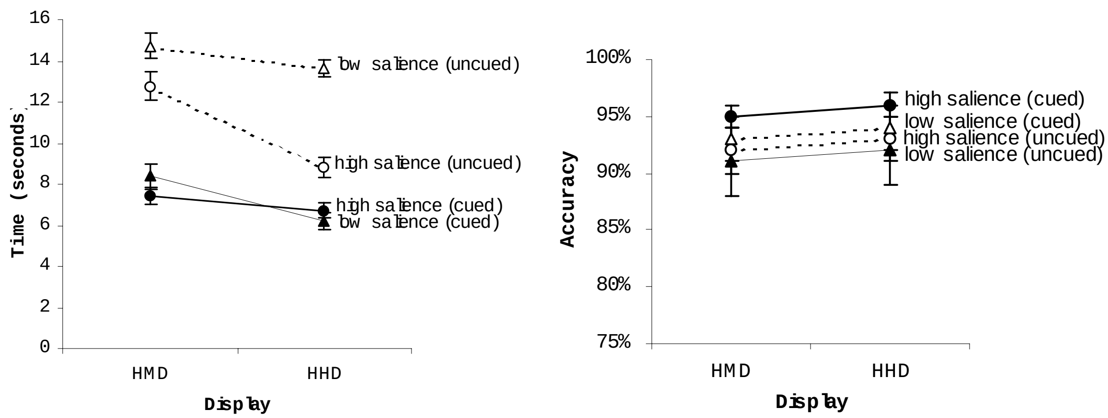

Figure 3.1.1. Effects of display location on target detection (a) response time and (b) accuracy.

The data in Figure 3.1.1(a) revealed that superimposing imagery onto the forward field of view imposed a time cost of approximately 3 seconds on target detection relative to the head down display, $F(1, 7) = 7.42$, $p < 0.05$. Although the overall display x target type interaction was not significant, $F(1, 7) = 0.66$, $p = 0.44$, a 2 (display) x 3 (wall) within-subjects ANOVA conducted for each target type revealed that the detrimental effects of clutter caused by the head-up location were greatest for the high salience soldiers (4s), which were never cued, $F(1, 7) = 14.28$, $p < 0.01$, less for the low salience land mines, $F(1, 7) = 4.44$, $p = 0.07$ (1.6s), and nonexistant for the always-cued tanks, $F(1, 7) = 0.74$, $p = 0.42$. The accuracy data revealed no effect of display, $F(1, 7) = 0.25$, $p = 0.63$. Taken collectively, the data suggest that superimposing imagery head-up, as it was implemented in the current paradigm, imposed a significant cost of clutter, and this cost was reflected in response time, rather than accuracy.

In order to assess the costs of scanning, the data were examined to assess how well subjects were able to divide their attention between the target detection task and the HMD imagery presented at the same location relative to the hand-held presentation of that same imagery at a head-down location. To measure this difference, a 2 (display) x 2 (cueing) ANOVA was conducted on the data for monitoring task performance. Note that the cueing factor in this analysis refers to the status of the target being searched. The latency and accuracy with which subjects responded to the monitoring task are presented in Figure 3.1.2.

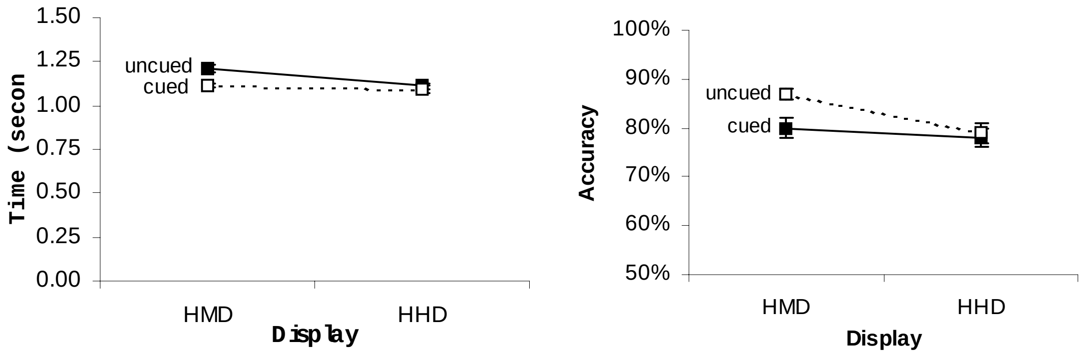

Figure 3.1.2. Effects of display location on monitoring detection: (a) response time and (b) accuracy.

The response time data shown in Figure 3.1.2(a) revealed no differences attributable to display, $F(1, 7) = 0.10$, $p = 0.76$, cueing, $F(1, 7) = 0.86$, $p = 0.38$, nor was the interaction between the two variables significant, $F(1, 7) = 0.07$, $p = 0.80$. The accuracy data (Figure 3.1.2(b)) also revealed no differences attributable to display, $F(1, 7) = 0.65$, $p = 0.44$, nor cueing, $F(1, 7) = 0.19$, $p = 0.67$. There was, however, a significant display x cueing interaction, $F(1, 7) = 9.61$, $p < 0.05$, suggesting that cueing diverted attention from the secondary task only when the cue (and secondary task) were presented on the HMD.

Thus, data portrayed in Figure 3.1.1, suggest that the costs of clutter outweigh the costs of scanning, and as Figure 3.1.2 shows, this cost was not offset by any benefit in secondary (monitoring) task performance. Subjects were better able to detect the target when information was presented head-down with no loss in performance to perform the monitoring task. Furthermore, a cue presented on an HMD has some disruptive effect on other displayed tasks, an effect that is not observed when the cue is presented on the HDD.

3.2 Cueing

In order to determine the effect of cueing, a comparison of the detection of cued versus uncued land mines was conducted. No comparisons were made between the two expected targets (cued tanks and uncued soldiers) as variables affecting performance could not be attributed solely to cueing, i.e., tanks were cued and soldiers were not, but there were also possible confounding differences attributable to in the physical appearance of the stimuli. The data for land mine detection were analyzed using a 2 (display) x 2 (cueing: cued vs. uncued) x 3 (wall: left, center, and right) within subjects ANOVA. The analysis revealed, as shown in Figure 3.1.1, that the availability of cueing substantially reduced detection time for the low salience land mines by around 7 seconds, $F(1, 7) = 35.83$, $p < 0.001$.

The effects of a subject’s expectation of a target was examined by comparing detection performance for tanks and soldiers – both highly expected targets – with detection of nuclear devices – infrequent, low expectation targets. Subjects were instructed that the latter were of higher priority. The nuclear device trials were separated into two classes based on whether the

nuclear device was presented concurrently with a cued tank or with an uncued soldier. The data are presented in Figure 3.2.1.

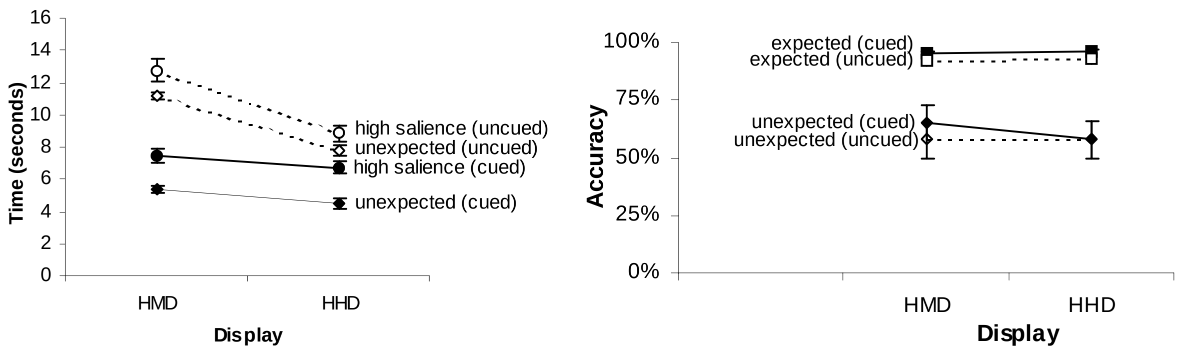

Figure 3.2.1. Attentional effects of cueing on (a) response time and (b) accuracy.

A main effect of display, $F(1, 7) = 6.84$, $p < 0.05$, suggested a response time advantage for the hand-held display, and a main effect of cueing, $F(1, 7) = 21.14$, $p < 0.01$ suggested that the presentation of a cue facilitated target detection. The significant interaction between display and cueing, $F(1, 7) = 7.75$, $p < 0.05$, suggested that the cost of the HMD was minimized on trials when the target to be sought was cued.

The accuracy data present a qualitatively different picture. Here, the data reveal significantly lower accuracy in detecting the unexpected object, $F(1, 7) = 22.58$, $p < 0.001$, but contrary to prior research (e.g., Yeh et al., 1999), there were no effects of display location, $F(1, 7) = 0.05$, $p = 0.83$, nor of cueing the concurrent target, $F(1, 7) = 0.92$, $p = 0.37$. The difference in this result relative to previous findings of attentional tunneling reported by Merlo et al. (1999) and Yeh et al. (1999) can be attributed to the less precise cue, which guided attention only to a 45° region, and hence would have included the location of the unexpected object, as it was placed within 15° of the expected target.

3.3 Scanning Strategies

A 2 (display) x 4 (target type) repeated measures ANOVA was conducted to measure differences in head motion along the *x*, *y*, and *z* axes. The results showed that the presentation of symbology using a head-down medium encouraged more head movement than with the HMD [approximately 23% more along the *x*-axis: $F(1, 7) = 4.66$, $p = 0.07$; 4 times more along the *y*-axis: $F(1, 7) = 9.12$, $p < 0.05$; and 13% more along the *z*-axis: $F(1, 7) = 3.69$, $p = 0.10$].

An analysis was also conducted in order to determine whether the location (or wall) on which the target item was presented played a role in subjects' ability to detect the target. A 2 (display) x 4 (target type) x 3 (wall) repeated measures ANOVA was conducted on the response times and accuracy for target detection. Figure 3.3.1 shows the results.

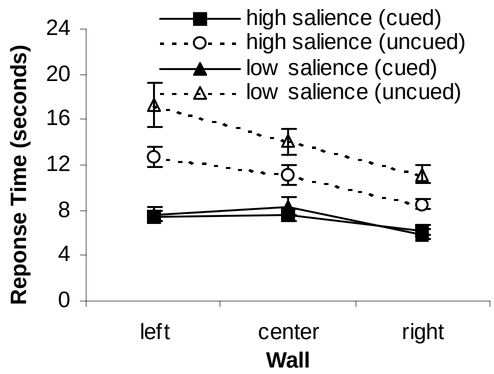

Figure 3.3.1. Response time and accuracy effects of scanning due to wall.

The data reveal a significant effect of target location, $F(2, 14) = 9.20$, $p < 0.01$, with subjects detecting targets on the right wall faster than those on the left [$F(1, 7) = 29{,}89$, $p < 0.001$] or center [$F(1, 7) = 29.89$, $p < 0.001$], with no differences in detection time between the left and center walls, $F(1, 7) = 0.92$, $p = 0.37$. The wall x display interaction was not significant, $F(2, 14) = 1.25$, $p = 0.32$.

The data revealed no differences in target detection accuracy as a function of target location, $F(2, 14) = 0.18$, $p = 0.84$.

4. DISCUSSION

The data revealed that the clutter cost outweighed the cost of scanning, as implemented in the current study. While these results at first glance seem contrary to that reported in the HUD domain (Fadden et al., 1998), the presentation of the symbology and the nature of the data that was displayed can easily account for the findings.

First, it is impossible to ignore differences in the opacity of the symbology. Although the imagery used in the current study was semi-transparent, its presentation directly in the forward field of view and the high level of detail used to present the topographical data likely reduced the visibility of information in the far domain that appeared behind the imagery to a greater degree than that of any HUD symbology, or of the very simplified imagery employed by Yeh et al. (1999). This is a cost associated with any head-up presentation of imagery.

Second, the imagery presented in the current experiment required a significant amount of display real estate; consequently, the clutter cost may have been greater than that imposed in the HUD studies. In fact, Ververs and Wickens (1998) reported that as more information became available, the costs of clutter begin to outweigh the costs of scanning.

In terms of capitalizing on cueing benefits, the results reveal that cueing attention to a wider region in space provides a means to obtain the benefits of cueing. The data presented in Figure 3.1.1(a) show that the presentation of cueing with only 45^{o} resolution did indeed facilitate target detection. More importantly, Figure 3.1.1(b) show that this benefit was obtained with no

loss in accuracy, regardless of target expectancy, thus, failing to reveal the attentional narrowing effects that had been observed previously by Yeh et al. (1999) and Merlo et al. (1999). However, it is important to note that since the unexpected target was located within 15° of the expected target, its presence was likely to be highlighted by the cueing information which guided attention to a 45° region of the far domain, a considerably less precise cue than that employed by Yeh et al. (1999). It would be interesting to examine whether tunneling occurs when the unexpected target is located outside of the cued region in order to fully assess the efficiency of this cueing symbology.

Analyses of the scanning data showed that subjects moved their head clockwise, similar to that used in reading text from left to right. Target detection data for stimuli presented without cueing showed faster target detection times on the right wall than on the left and center wall (Figure 3.3.1). The data suggests that subjects sometimes turned their head from the center wall, where the head was positioned at the start of each trial, to the right immediately after the trial began. That is, when the target was within the subject's field of view on the center wall, subjects occasionally did not notice the target or attempt to search the center wall but instead turned their head clockwise, preferring to search the right wall first. If the target was not found on the right wall, subjects then moved their head back to the center and searched that wall for objects before examining the left wall. These results are similar to those reported by Yeh et al. (1998).

It is not surprising that the head down display fostered much more vertical head movement than did the HMD. Somewhat less expected was the restriction in lateral head movement with the HMD, relative to the HDD. We cannot attribute this to the differences in weight, as was the case with similar observations by Yeh et al. (1999), since subjects were equally encumbered with a helmet in both conditions.

In conclusion, it is important to note that the amount of data presented in the current study is only a very small subset of the information to be displayed to the ground soldier of the future, yet the data already show the detrimental costs to clutter. As the head-up presentation of tactical data is further examined, it is important to evaluate methods for decluttering the information (e.g., by moving information out of the forward field of view when it is not necessary or "erasing" it temporarily) and the potential consequences for doing so, e.g., the cost of failing to detect a change in the "decluttered" domain (Wickens, Kroft, & Yeh, 2000).

ACKNOWLEDGEMENTS

The authors would like to thank Ron Carbonari for his time, expertise, and patience in programming the application, and Hank Kaczmarski for his help in integrating the hand-held display with the CAVE hardware. Finally, we would like to thank Sgt. Michael McMullen and all the Illinois National Guard personnel who participated in the experiment. This material is based upon work supported by the U.S. Army Research Laboratory under Award No. DAAL 01-96-2-0003. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the U.S. Army Research Laboratory.

REFERENCES

Fadden, S., Ververs, P., & Wickens, C.D. (1998). Costs and benefits of head-up display use: A meta-analytic approach. Proceedings of the 42nd Annual Meeting of the Human Factors & Ergonomics Society. Santa Monica, CA: Human Factors Society.

Merlo, J.L., Wickens, C.D., & Yeh, M. (1999). Effect of reliability on cue effectiveness and display signaling (Technical Report ARL-99-4/FED-LAB-99-3). Savoy, IL: University of Illinois, Aviation Res. Lab.

Ververs, P. M., & Wickens, C. D. (1998). Head-up displays: Effects of clutter, display intensity, and display location on pilot performance. The International Journal of Aviation Psychology, 8(4), 377-404.Wickens, Kroft, & Yeh, 2000).

Wickens, C.D., Kroft, P., & Yeh, M. (2000). Data base overlay in electronic map design: Testing a computational model. Proceedings of the IEA 2000/HFES 2000 Congress (pp. 3-451-3-454). Santa Monica, CA: Human Factors & Ergonomics Society.

Yeh, M., Wickens, C.D., & Seagull F.J. (1998). Effects of frame of reference and viewing condition on attentional issues with helmet-mounted displays. Proceedings of the 2nd Annual FedLab Symposium: Advanced displays & interactive displays (pp. 107-114). College Park, MD: U.S. Army Research Federated Laboratory Consortium.

Yeh, M., Wickens, C.D., & Seagull, F.J. (1999). Target cueing in visual search: The effects of conformality and display location on the allocation of visual attention). Human Factors, 41(4), 524-542.